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## **Advanced Laser and RF Plasma Sources and Diagnostics**

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**Final Report**

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14. ABSTRACT <p>We have made substantial research progress during the past three years with highlights including: Measurements of 193 nm (6.42 eV photon) laser quantum-resonant multi-photon absorption and ionization (REMPI) processes in air that produce breakdown (<math>n &gt; 10^{14}/\text{cc}</math>) for rf moderate density (<math>10^{12}/\text{cc}</math>), sustainment at lower (<math>&lt; 2 \text{ kW}</math>) coupled power levels with 200 cc volumes. Millimeter wave interferometry and optical emission spectroscopy measurements of laser focused seed air plasmas with improved matching for rf-sustainment have produced high densities (<math>n_e &gt; 10^{12}/\text{cc}</math>), at much higher initial pressures (80 torr) than can be obtained with rf alone (45 torr). Production of plasma rf self bias accelerated argon ion beams with the highest beam energies per Watt in the literature (165 eV at 500 W rf power). This accomplishment includes substantially exceeding the research results of helicon double layer ion acceleration research from Australia, Europe, Russia and the United States, including a detailed description axial ion beam evolution. The results of this research are described in six reviewed scientific journal articles in the Physics of Plasmas, the Jour. of Applied Physics and the IEEE Jour. of Plasma Science.</p>					
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# Grant Title: Advanced Laser and RF Plasma Sources and Diagnostics

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## Grant Accomplishments

We have made substantial research progress during the past three years with highlights including:

1. Measurements of 193 nm (6.42 eV photon) laser quantum-resonant multi-photon absorption and ionization (REMPI) processes in air that produce breakdown for rf moderate density ( $10^{12}/\text{cc}$ ) sustainment at lower ( $< 2$  kW) coupled power levels with 200 cc volumes.
2. We published a paper in the Jour. of Applied Physics (see below) describing the initial laser seed plasma-rf sustainment startup pressure improvement over the fixed rf coupled power alone maximum pressure case of 18 torr.
3. Millimeter wave interferometry and optical emission spectroscopy measurements of these improved laser focused seed air plasmas with improved matching for rf-sustainment have produced high densities ( $n_e > 10^{12}/\text{cc}$ ), at much higher initial pressures (80 torr) than can be obtained with rf alone (45 torr). We are currently carrying out rf power and pressure scans.
4. Production of argon ion beams with the highest beam energies per Watt in the literature (165 eV at 500 W rf power) resulting two publications (see below) in the Physics of Plasmas peer-reviewed journal. This accomplishment includes substantially exceeding the research results of helicon double layer ion acceleration research from Australia, Europe, Russia and the United States, including detailed axial ion beam evolution. Our publications describe the ion beam energy that considerably exceeds the ambipolar potential as one moves through the acceleration region and the electron temperature and density. The papers also describe the significant plasma potential “self bias” effect that occurs due to excess electron transport from the rf source region on the rf timescale and the residual ion concentrations that give rise to the ion acceleration.
5. We have developed, loaned and provided technological support for our Andor GenIII intensified charge coupled device (ICCD) with high temporal resolution (1-50 ns gate) and our Acton 0.5 m high resolution spectrometer for a companion research program (AFOSR USDOD Multi-University Grant on Basic Physics of Distributed Plasma Discharges) to observe fast time- and space-resolved distributed, high-power microwave breakdown processes and measure optical emission to determine the microwave breakdown gas temperatures.
6. We have published three (6) reviewed journal papers, and contributed fifteen (15) ICOPS and APS plasma conference oral papers and posters that presented the results of our research during the above grant period.

7. We have designed and upgraded the MadHeX magnetic field expansion configuration to minimize the collisions of the accelerated ion beam and plasma with the expansion chamber to minimize neutral reflux and reduce neutral concentrations in the expansion chamber.
8. We have developed new measurement techniques to determine the calibrated Ar excited state optical emission characteristics and transpiration measurements of ground state neutral gas pressure and temperature. These measurements will be utilized to collaborate with Dr. John Bofford and Professor Amy Wendt (supported by NSF), who have developed a spectroscopic code that can determine the electron energy distribution function including possible fast electron tail generation for a wide range of plasma and power conditions in our MadHeX experimental facility.
9. Graduate Students Matt Wiebold, Ryan Giar, Yung-Ta Sung, Yan Li and Michael DeVinney have substantially contributed to this research.

## Reviewed Journal Publications (6)

1. Research on the mechanism for fast ion beam acceleration has been published by M. Wiebold, Y. T. Sung, J. E. Scharer. "*Ion acceleration in a helicon source due to the self-bias effect.*" *Physics of Plasmas*, **19** (053503, 11 journal pages), May 2012
2. Matt Wiebold, Yung-Ta Sung and John E. Scharer, *Physics of Plasmas* "*Experimental observation of ion beams in the Madison Helicon eXperiment.*" *Physics of Plasmas*, **18** (063501, 10 journal pages), June 2011.
3. R. Giar and J. Scharer, "*Focused Excimer Laser Initiated, RF Sustained High Pressure Air Plasmas.*" *Journal of Applied Physics* **110** (103301, 9 journal pages), Nov. 2011.
4. Work in the laser-initiated, rf sustained plasma lab has resulted in the publication of a paper by Jason Hummelt and John Scharer, "*Excitational Energy Transfer Ionization and Spatial-Temporal Air Breakdown with Ultraviolet Laser Radiation*" *Jour. Applied Physics*, **108** (093305), Nov. (2010) [7 journal pages].
5. Jesse Way, Jason Hummelt, and John Scharer, "*Experimental Measurements of Multiphoton Enhanced Air Breakdown by a Sub-threshold Intensity Laser*", **106** (083303), [8 journal pages] Oct. 2009
6. M. Wiebold, H. Ren, J. E. Scharer, C. M. Denning. "*Low Pressure Helicon Discharge Initiation Via Magnetic Field Ramping.*" *IEEE Transactions on Plasma Sciences*, **37** (2110-2115)[ 6 journal pages], Nov. 2009

**Invited Paper:**

High Frequency Gaseous Breakdown Research on Distributed Plasma Discharges\* - J. Scharer<sup>1</sup>, J. Booske<sup>1</sup>, R. Gilgenbach<sup>2</sup>, R. Temkin<sup>3</sup>, A. Neuber<sup>4</sup>, J. Verboncour<sup>5</sup> et al; University of Wisconsin, Madison<sup>1</sup>, University of Michigan<sup>2</sup>, MIT<sup>3</sup>, Texas Tech University<sup>4</sup> and University of California, Berkeley<sup>5</sup>, USA; High Frequency Breakdown Workshop, Gaseous Electronics Conference, Paris, France, October 4, 2010. Results of our laser quantum multi-photon air breakdown research were included in the presentation.

**Conference Publications (15) Presentations at IEEE Plasma Science, Gaseous Electronics and American Physical Society Conferences**

**New discoveries, inventions or patent disclosures: None**